

# A Study of Friction Stir Welded 2195 Al-Li Alloy by the Scanning Reference Electrode Technique

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National Aeronautics and  
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## **TECHNICAL PAPER**

# **A STUDY OF FRICTION STIR WELDED (FSW) 2195 AL-LI ALLOY BY THE SCANNING REFERENCE ELECTRODE**

## **1. INTRODUCTION**

The corrosion of aluminum alloys is generally measured on a macroscopic scale using a relatively large surface area of a test specimen and measuring the corrosion currents. However, the corrosion is generally not uniform on a microscopic scale, as evidenced by pitting in many cases. Recent work with aluminum-lithium alloys indicates that they are susceptible to pitting corrosion<sup>1</sup>, a localized corrosion phenomenon. Recently a technique has been developed that allows the measurement of localized corrosion and is called the scanning reference electrode technique (SRET). This report describes the results obtained from friction stir welded 2195 Al-Li, an autogenous welding technique (no filler is used), and compares these results with those obtained from heterogeneously welded 2195 Al-Li using 4043 filler. The variable polarity plasma arc (VPPA) weld process was used for the heterogeneous welds.

## **2. FRICTION STIR WELD (FSW) AND VPPA WELD PROCESS DESCRIPTIONS**

This study employs the FSW process to investigate corrosion susceptibility of aluminum alloy 2195. Similar work has already been completed using the VPPA weld process. The primary difference between FSW and VPPA is that the FSW process is solid state, i.e., the material weld does not melt during welding. Maximum welding temperatures (aluminum 2195) are approximately 400° below melting. Generation of heat is purely mechanical. Frictional heat is generated when the steel shoulder of the pin-tool rubs on the surface of the material to be joined. There is no requirement for filler material nor shielding gas. VPPA is a fusion weld process, thus, melting material during the weld process. The VPPA process is a derivative of plasma arc welding (PAW), incorporating a variable current waveform characteristic in the arc. Aluminum alloy 2195 requires both filler material (4043 filler wire) and shielding gas.

### 3. THE SCANNING REFERENCE ELECTRODE TECHNIQUE (SRET)

The SRET instrument shown in figure 1 is commercially available from EG&G Princeton Applied Research Corp. (EG&G-PARC). It has the capability to measure micro-galvanic potentials close to the surface of materials, and it allows in situ examination and quantification, on a microscopic scale, of electrochemical activity as it occurs. The SRET is microprocessor controlled, and electrical potentials are measured by a special probe capable of translation in the  $x$ - and  $y$ - directions. The specimen, in the form of a cylinder, is held in a vertical position and rotated around the  $y$ -axis. The scan is synchronized with a display monitor and the resultant data are shown in the form of line scans or 2-dimensional area maps. The width of the area maps ( $x$ -direction) can be set at will using the zoom-in feature of the experimental setup. The height of the area maps ( $y$ -direction) is set automatically by the control software according to the proper aspect ratio. Movement of the scanning probe during data collection is in the  $y$ -direction. Direct measurement of surface potentials, showing anodic and cathodic areas, at discrete positions on the sample surface, may be taken and stored for time-related studies. Because the minimum detectable signal (MDS) is of the order of 1 mA/cm<sup>2</sup>, a potential must be applied to the sample to increase the corrosion current to at least this level, accomplished by means of a separate potentiostat (EG&G-Parc Model 273A Potentiostat/Galvanostat) coupled to the SRET system.



Figure 1. The scanning reference electrode system  
(A-metal sample; B-probe; C-counter electrode)

#### 4. EXPERIMENTAL PROCEDURE

The sample for the friction stir welded specimen was prepared from a 2195 Al-Li plate ~1.651 cm (0.650 in.) thick. The welding pin-tool consisted of a 1.27-cm (0.500-in.) diameter cylinder 1.27 cm (0.500 in.) long protruding from a 1.1-in. diameter shoulder. The pin-tool was rotated at 400 rpm and inserted into the weld joint. The pin-tool traversed the weld joint at 4 in./min. A 1.27-cm (0.45-in.) diameter cylinder with a 10.1-cm (4.0-in.) length, with weld extending completely along its length, was machined from the bottom of the plate, so that the upper 0.25 cm (0.10 in.) of the cylinder consisted of weld.

For the experiment, the test specimen was mounted in the collet of the SRET, and the probe, counter electrode, and reference electrode were also placed in their positions in the machine. The probe was moved to a position so that its tip was ~0.5 mm from the surface of the sample. The entire assembly was immersed in a corrosive medium of 3.5-percent sodium chloride (NaCl) solution so that about a 5.1-cm (2-in.) length of the metal sample rod was exposed to the corrosive medium. A potential of 650 mV was then applied to the sample by a computer-controlled EG&G model 273A potentiostat to bring the corrosion current up to that required to achieve the minimum detectable signal level. This potential is approximately three times that required for the heterogeneously welded (VPPA-welded) sample, implying that the corrosion rate is less than that for the heterogeneously welded sample. During data collection, the sample was rotated at 100 rpm. The sample was oriented so that the weld would appear approximately in the center of the map scan. Map scans were taken beginning and ending at equal distances from the zero point of the SRET, such that a distance of 3.0 cm of the sample circumference was displayed on the map ( $x$ -direction). The experiments were set up in such a way that all maps had a width of 3.0 cm ( $x$ -direction) and a height of 2.25 cm ( $y$ -direction).

A total of four area maps were collected for the autogenously welded sample, with a 1-hour delay between each. After completion of each map scan, the data were stored in a separate file for later display and measurement. After data collection was completed, each map was displayed on the computer screen and the proper palette (color scheme) for display of the map features was selected. Measurements of the topography of the various map features (potentials for anodic and cathodic regions) were obtained using software developed for this purpose.

## 5. RESULTS AND DISCUSSION

Potential maps for unwelded 2195 Al-Li are shown in figures 2 and 3. These maps are not striated, but show alternating sequences of anodic and cathodic regions. Maps for heterogeneous (VPPA) welds are shown in figures 4 and 5. Here, the features are striated parallel to the weld seam. Anodic regions are obtained in the heat-affected zone (HAZ) or partially melted zone (PMZ) at the edges of the weld. The potential required to reach the MDS level was 200 mV in this case. It has been observed that corrosion and pitting occur at the edges of these welds. Maps for autogenously welded 2195 Al-Li are shown in figures 6 and 7. Again, these maps show striated regions parallel to the weld direction, with anodic regions at the edges of the weld. The weld is again cathodic in nature, as was the case for the VPPA weld. The main difference is that this weld is broader than that obtained for the heterogeneous weld. The potential required to obtain the MDS level was 600 mV in this case, suggesting that the autogenously welded (FSW) material is less subject to corrosion than the heterogeneously welded material.

Normal corrosion rates for both heterogeneously welded and autogenously welded 2195 Al-Li have been determined in a mild corrosive water medium (148 mg/l sodium sulfate, 165 mg/l sodium chloride and 138 mg/l sodium carbonate)<sup>2</sup>. These were 0.212 mils/year (mpy) for the heterogeneous welds and 0.109 mpy for the autogenously welded sample. Thus, the observation in the present study is in agreement with the normal corrosion rates which have been observed.

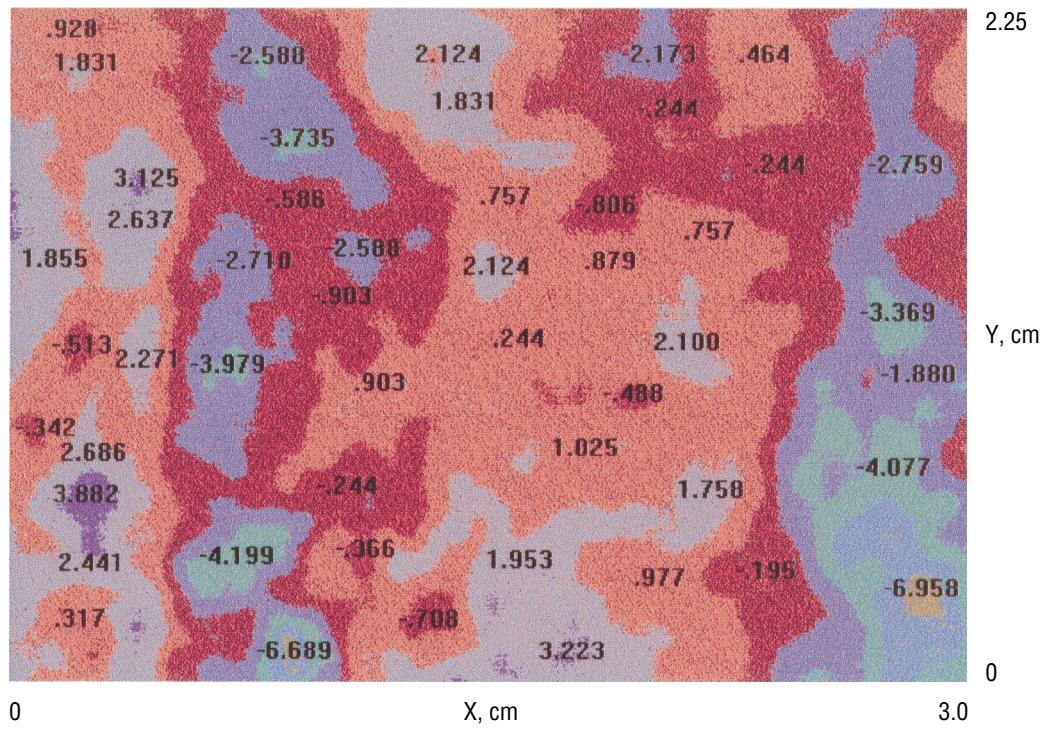


Figure 2. Unwelded 2195 Al-Li alloy after 2 hours

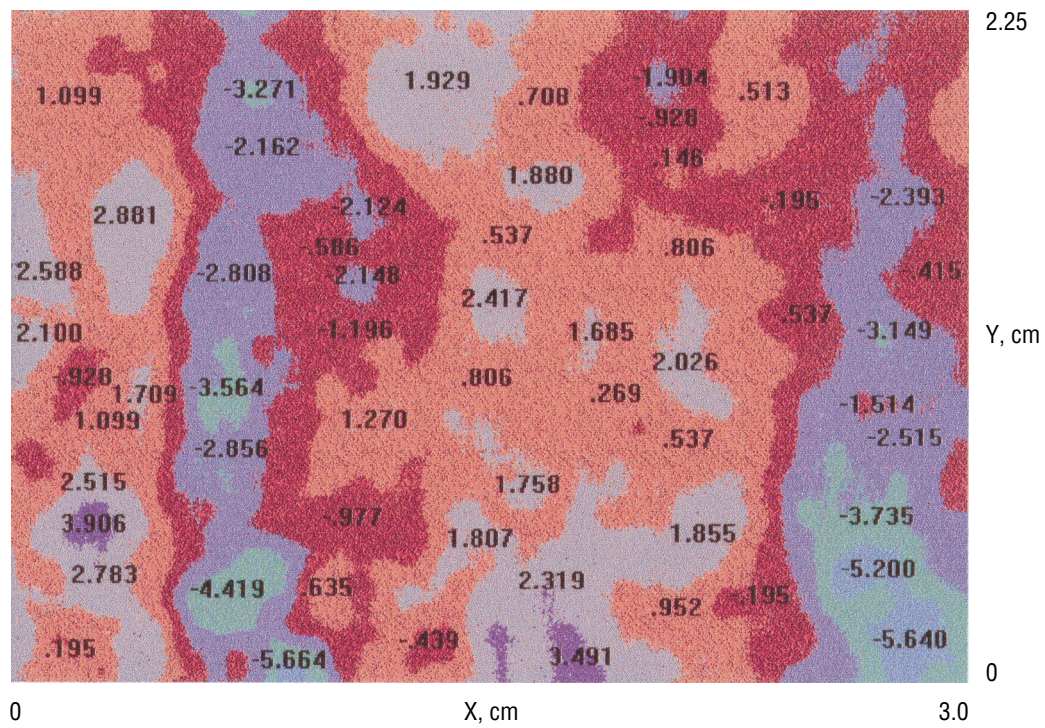


Figure 3. Unwelded 2195 Al-Li alloy after 3 hours

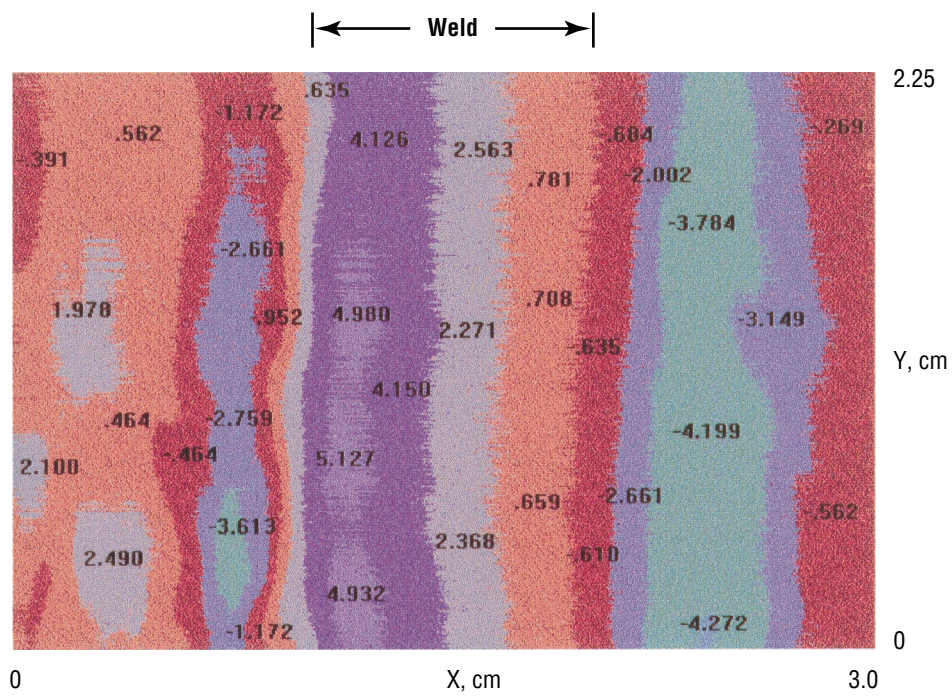


Figure 4. Localized corrosion in 2195 Al-Li weld (4043 filler) after 2 hours

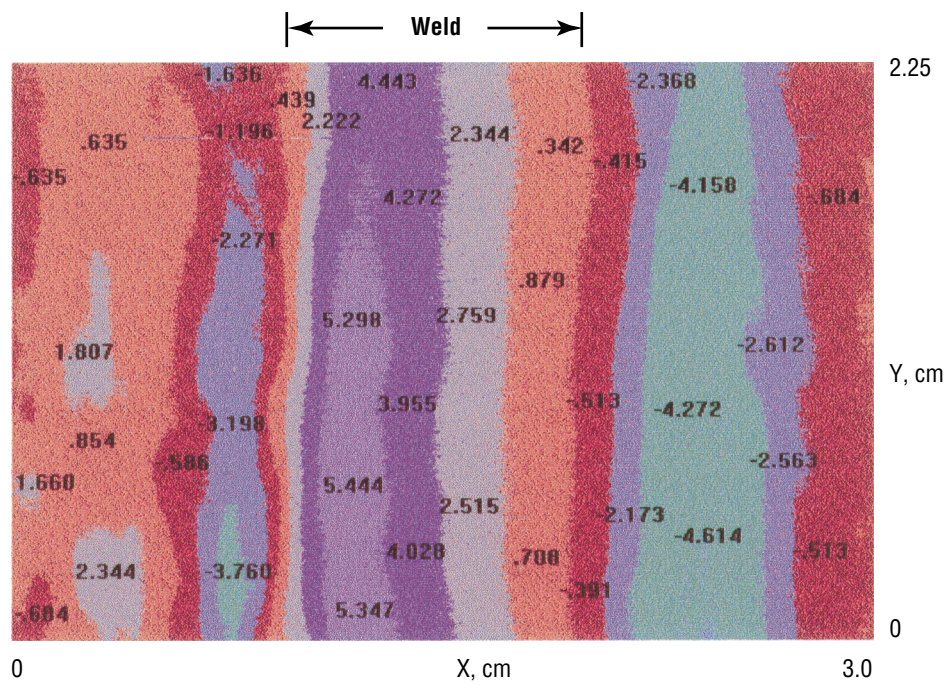


Figure 5. Localized corrosion in 2195 Al-Li weld (4043 filler) after 3 hours

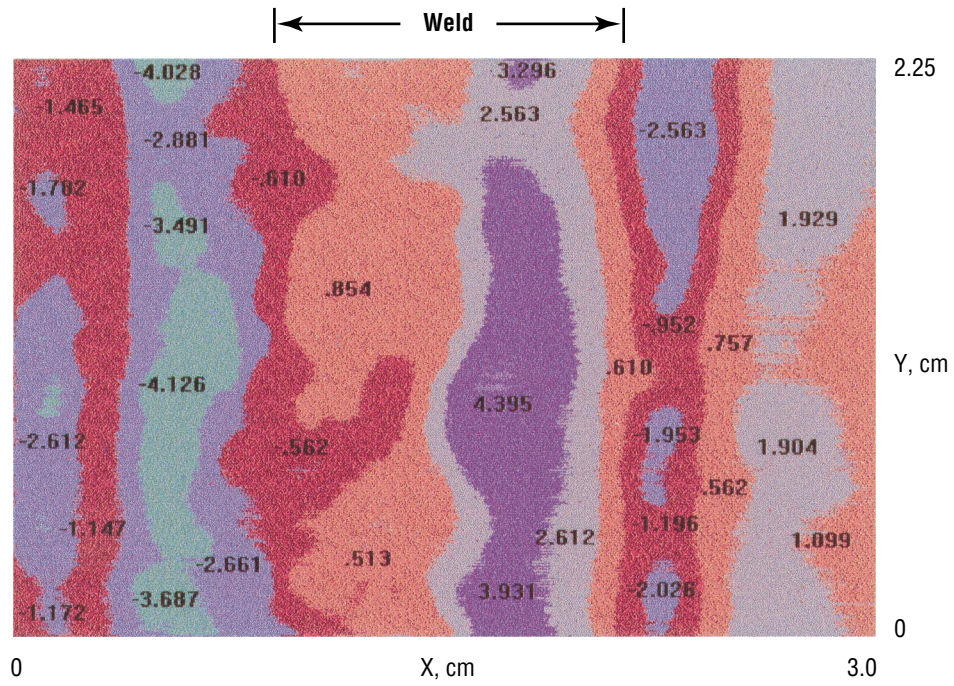


Figure 6. Localized corrosion in friction stir welded 2195 Al-Li after 2 hours

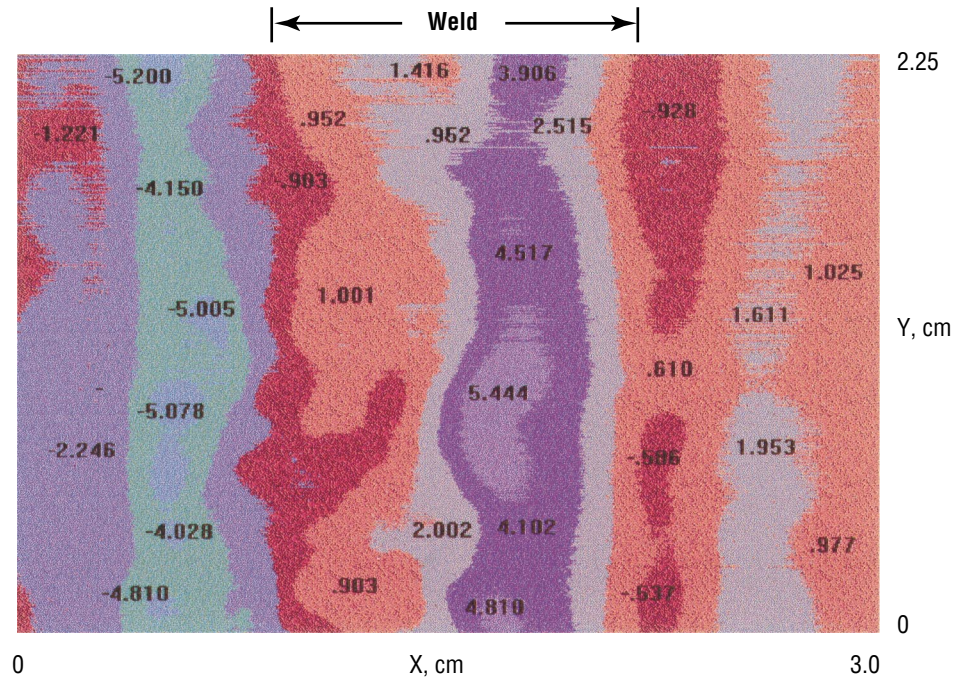


Figure 7. Localized corrosion in friction stir welded 2195 Al-Li after 3 hours

## **6. CONCLUSIONS**

Results for friction stir welded (autogenously welded) samples show patterns similar to those obtained for VPPA-welded or heterogeneously welded samples. The results also suggest that friction stir, or autogenous, welds are less subject to corrosion, in agreement with results obtained from studies of the normal corrosion rates obtained for these two types of welding. The FSW welds are also cathodic in nature, as was the case for VPPA-welded samples.

## **REFERENCES**

1. Walsh, D.W.: Unpublished results.
2. Walsh, D.W.: Summer faculty participant, California Polytechnic Institute, San Luis Obispo, CA, 1994.



REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operation and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503				
1. AGENCY USE ONLY (Leave Blank)		2. REPORT DATE March, 1998		3. REPORT TYPE AND DATES COVERED Technical Publication
4. TITLE AND SUBTITLE A Study of Friction Stir Welded 2195 Al-Li Alloy by the Scanning Reference Electrode Technique				5. FUNDING NUMBERS
6. AUTHORS M.D. Danford and M.J. Mendrek				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) George C. Marshall Space Flight Center Marshall Space Flight Center, Alabama 35812				8. PERFORMING ORGANIZATION REPORT NUMBER  M-858
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001				10. SPONSORING/MONITORING AGENCY REPORT NUMBER  NASA/TP-1998-207399
11. SUPPLEMENTARY NOTES  Prepared by Materials and Processes Laboratory, Science and Engineering Directorate				
12a. DISTRIBUTION/AVAILABILITY STATEMENT  Unclassified-Unlimited Subject Category 26 Standard Distribution				12b. DISTRIBUTION CODE
13. ABSTRACT (Maximum 200 words)  A study of the corrosion of friction stir welded 2195 Al-Li alloy has been carried out using the scanning reference electrode technique (SRET). The results are compared to those obtained from a study of heterogeneously welded samples.				
14. SUBJECT TERMS localized corrosion, friction stir welds, electrochemical methods.				15. NUMBER OF PAGES 16
				16. PRICE CODE A03
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT Unlimited	